ÖGH Herpetozoa
Austrian Herpetological Society

Herpetozoa 37: 347–358 (2024)
DOI 10.3897/herpetozoa.37.e130028

# Water bodies created by peatland restoration are potential habitats for amphibians and reptiles

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Academic editor: Andreas Maletzky ♦ **Received** 19 June 2024 ♦ **Accepted** 27 September 2024 ♦ **Published** 11 November 2024

## Abstract

In Lower Austria's Waldviertel region, artificial drainage ditches were constructed in the last century in order to use peatlands for forestry, agriculture, and peat extraction. By now, many of these peatlands are part of the Natura 2000 network and therefore gradually undergo restoration measures, which aim to rewet the peatlands. For this, the ditches are blocked with wooden dams, leading to a water runback, which in turn fills the ditches and peat pools. Such artificial water bodies generally depict secondary habitats for many species. Here, we investigated the amphibian fauna in four restored peatlands in the Waldviertel region and measured abiotic factors of the aquatic habitats to answer the question whether blocked ditches and peat pools are valuable secondary habitats for amphibians. We characterized the microhabitats of amphibians based on various structures and vegetation. Additionally, this study provides a basic assessment of reptile species in the investigated peatlands. During our assessment, we observed 1520 individuals of eight amphibian species, 64 individuals of four reptile species, and characterized 12 different microhabitats. Despite the low pH values of 3.2–4.2, four amphibian species and amphibian spawn were detected in Schwarzes Moos. Our results indicate that peat pools, drainage ditches, and open moorlands are potential habitats for amphibians and reptiles, making their conservation and management an important factor in the protection of amphibian and reptile species.

## Key Words

acid tolerance, Austria, blocked drainage ditch, conservation, microhabitats, Natura 2000, peat pools, reptiles, Waldviertel

## Introduction

Worldwide, peatlands suffer from destruction, pollution, and climate change (Holden et al. 2007; Joosten 2009; Davidson 2014; Bonn et al. 2016). These ecosystems are highly important for ecology, storing water, carbon, and nutrients in high amounts and representing essential habitats for many species (Lamers et al. 2015). In Austria, more than 90% of the peatlands were destroyed (Dewitz 2023). The particularities of this ecosystem are the acidity of the substrate, the water regime, the fast-changing microclimate, and the low availability of nutrients, which lead to the presence of many highly specialized plant and animal species (Jungmeier et al. 2004; Dierßen and Dierßen 2008).

In the past, artificial drainage ditches were created to dry the soil so that the peatlands could be used for forestry and agriculture and to extract peat. This drains the water directly and lowers the water level (Dierßen and Dierßen 2008). These artificial ditches destroy peat formation and alter soils, vegetation, hydrology, hydrochemistry, and biodiversity (Suislepp et al. 2011; Lõhmus et al. 2015). Along with this, the growing tree coverage in peatlands increases transpiration, which leads to even more desiccation (Succow and Joosten 2001; Dierßen and Dierßen 2008). At the same time, natural water bodies are being

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converted into linear water networks, leading to a restructuring of the species composition (Vaikre et al. 2020).

In Lower Austria's Waldviertel region, many remaining peatlands are part of the Natura 2000 Network and therefore gradually undergo restoration measures (Provincial Government of Lower Austria 2009). The main aim of the restoration measures is to rewet the peatlands. For this purpose, the artificial ditches are blocked with wooden dams, leading to a water runback, which in turn fills the ditches and the peat pools. Such artificial water bodies generally depict secondary habitats for many animal species (Babik and Rafinski 2001; Tichanek and Tropek 2015; Vaikre et al. 2020). Secondary habitats such as blocked ditches can play an important role for amphibians in protected peatland areas (Hartel et al. 2011; Remm et al. 2018). Water-depth increases with ditch-blocking, which in turn enhances amphibian breeding in the long term (Soomets et al. 2023). However, Remm et al. (2018) found that ditches left to natural succession are less valuable habitats for brown frogs (*Rana arvalis* and *R. temporaria*). Shading by dense tree canopies and increased growth of sphagnum mosses (which results in siltation) negatively affect amphibian reproduction (Soomets et al. 2017; Remm et al. 2018), whereas a decrease in canopy shade increased amphibian breeding and the number of amphibian species in the year following the removal of brushwood (Soomets et al. 2017).

Natural peatlands provide important habitats for amphibians (Desrochers and Van Duinen 2006), which is especially important as amphibians are highly endangered across the world (Gibbons et al. 2000; Stuart et al. 2004). Due to their semi-permeable skin and their aquatic phase, amphibians are particularly susceptible to the acidity (pH value) of the water (Sparling et al. 2000). Although peatlands are acidic, several amphibian species are known to inhabit peatlands, e.g., Green Frogs (*Aquarana clamitans*) use peatlands as summer habitats (Mazerolle 2005), and the spawn and larvae of the Moor Frog (*R. arvalis*) are resistant to acids and therefore able to inhabit acidic-mesotrophic habitats (Räsänen et al. 2003; Glandt 2008; Burmeister 2015).

In this study, we explore whether blocked ditches and peat pools are valuable secondary habitats for amphibians in the Waldviertel region. We characterized microhabitats and measured abiotic factors (including pH values) to find out whether the restored peatlands provide habitats for amphibians. Additionally, as there was only limited data available for peatlands (especially for reptile species), this study will serve as a baseline inventory of amphibians and reptiles for future studies in this region.

## Methods

We investigated the amphibian and reptile fauna in four peatlands in the Waldviertel region and measured abiotic factors of the aquatic habitats. We chose four peatlands (Haslauer Moor, Heidenreichsteiner Moor, Schremser Hochmoor, and Schwarzes Moos) due to the presence of water bodies (peat pools and/or blocked ditches), open moorlands, and accessibility. Additionally, we characterized the microhabitats of amphibians and reptiles based on various structures and vegetation.

## Study site

The study took place in the Natura 2000 site 'Waldviertler Teich-, Heide- und Moorlandschaft' (Flora-Fauna-Habitat Directive (FFH Directive)) and "Waldviertel" (Birds Directive), in the Lower Austrian Waldviertel region (district Gmünd). The Natura 2000 site includes different priority habitat types defined by the FFH Directive (Ellmauer et al. 1999). The Waldviertel region is at the border of subcontinental and suboceanic climates, characterized by cold temperatures and moderate rainfalls (Jungmeier et al. 2004). The nearest weather station in Litschau (sea level: 558 m) records a mean annual air temperature of 7.1 °C and a mean annual rainfall of 844 mm (ZAMG 2017). The Waldviertel region in the northwest of Lower Austria is part of the Bohemian Mass, characterized by many large acidic-mesotrophic forest peat bogs, dominated by *Pinus sylvestris* (Steiner 1992; Pfundner 2021). The carbonate-free bedrock is impermeable, which, in addition to the low temperatures typical for this region, forms a low-nutrient and highly acidic soil (Pruckner 2002; Pranjič et al. 2006).

## Peatlands

Each of the four investigated peatlands contains water bodies (water-filled peat pools and/or blocked drainage ditches) (Fig. 1). The four sites are acidic, low in nutrients, and supplied by rainwater (Steiner 1992; Pranjič et al. 2006). The main habitats are bog forests with red pine (*P. sylvestris*) and wild rosemary (*Ledum palustre*), upland bogs with bog pine (*P. mugo*) and wild rosemary, and silted-up peat pools.

All four sites are medium to heavily damaged from past peat extraction, and large parts of the Waldviertler peatlands were destroyed by forestry, which, along with neophytes and tourism, continues to threaten them today (Penz 2000; Pfundner 2021). Different restoration projects took place in the Natura 2000 site, which aimed to rewet the peatlands and stabilize the water levels by damming/blocking drainage ditches (Pfunder 2021). From 2017–2021, the four sites, among others, were part of the cross-border INTERREG project "Crossborder Habitat Network and Management," which aims to restore the peatlands (Pfundner 2021). From 1991–2000 the Worldwide Fund for Nature (WWF) and a LIFE project from 1996–1999 took place at the Haslauer Moor and Heidenreichstein in which dam constructions and clearing of the central peatland areas were conducted to rewet the peatlands (Egger 2000; Seehofer et al. 2003; Ebhart 2011).

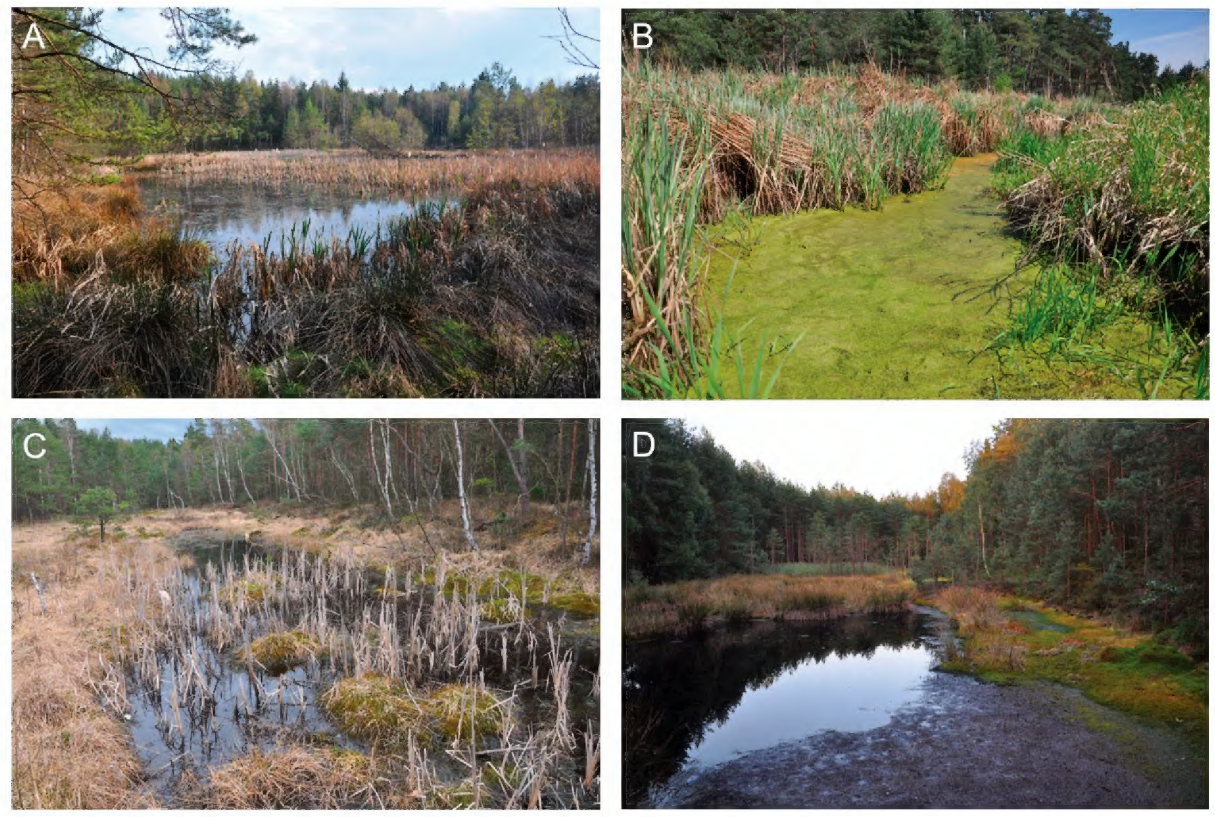


**Figure 1.** The four investigated peatlands in the Waldviertel region. **A.** A large peat pool in the Haslauer Moor; **B.** A blocked, water-filled drainage ditch in Heidenreichstein; **C.** A silting peat pool in Schrems; and **D.** A partly silting pool in the Schwarzes Moos.

In the Schremser Hochmoor, from 2003–2006, the project "Ländliche Entwicklung" conducted different restoration steps to rewet the peatland (Provincial Government of Lower Austria, 2009).

The Haslauer Moor (48.82472'N, 15.09889'E (WGS 84)) is located in the municipality Haslau. The peatland had an initial size of about 120 ha, of which only about 30 ha exist today (Egger 2000; Jungmeier et al. 2004). The Heidenreichsteiner Moor (48.85444'N, 15.14444'E (WGS 84)) in the municipality Heidenreichstein is part of the protected landscape (IUCN category V) "Naturpark Heidenreichsteiner Moor," which is approximately 30 ha large (http://www.moornaturpark.at, accessed on 31.07.2023). The Schremser Hochmoor (48.79861'N, 15.10000'E (WGS 84)), located in the municipality of Schrems and also part of a protected landscape ("Naturpark Hochmoor Schrems"), is the largest of the four peatlands. The peatland is 107 ha in size (Natura 2000 standard data form). The peatland Schwarzes Moos (municipality Brand-Altnagelberg; 48.871944'N, 14.980556'E (WGS 84)) is next to the Czech border. Originally, the peatland was 54 ha in size, but due to the former glass industry and strong forestry, only 1 ha of the peatland is preserved (Pranjič et al. 2006). The site consists of several water-filled peat pools and drainage ditches in different silting stages inside a private forest (Table 1).

According to the herpetofaunistic database of Austria (HFDÖ), six reptile and nine amphibian species are potentially located in the area of the study site: *B. bufo* (Common Toad), *Hyla arborea* (European Tree Frog), *Ichthyosaura alpestris* (Alpine Newt), *L. vulgaris* (Smooth Newt), *Pelophylax* kl. *esculentus* (Edible Frog), *P. lessonae* (Pool Frog), *R. arvalis* (Moor Frog), *R. dalmatina* (Agile Frog), *R. temporaria* (Common Frog), *Anguis fragilis* (Slow Worm), *Coronella austriaca* (Smooth Snake), *Lacerta agilis* (Sand Lizard), *Natrix natrix* (Grass Snake), *Vipera berus* (Adder), and *Zootoca vivipara* (Viviparous Lizard), of which five species are listed as "vulnerable" by the IUCN (*H. arborea*, P. *lessonae*, *R. arvalis*, *C. austriaca*, *V. berus*).

**Table 1.** Size and type of waterbodies of the investigated peatlands.

| Number | Type of water body | Size of water body | Location |
|---|---|---|---|
| 01 | water-filled peat pools | ~ 200 m² | Haslauer Moor |
| 02 | water-filled peat pools | ~ 250 m² | Haslauer Moor |
| 03 | blocked drainage ditch | ~ 100 m² | Heidenreichstein |
| 04 | water-filled peat pools | ~ 250 m² | Schrems |
| 05 | water-filled peat pools | ~ 2000 m² | Schrems |
| 06 | water-filled peat pools | ~ 80 m² | Schwarzes Moos |
| 07 | water-filled peat pools | ~ 100 m² | Schwarzes Moos |
| 08 | water-filled peat pools | ~ 120 m² | Schwarzes Moos |
| 09 | water-filled peat pools | ~ 800 m² | Schwarzes Moos |
| 10 | water-filled peat pools | ~ 1050 m² | Schwarzes Moos |

## Amphibian assessment

The amphibian assessment took place eight times, mainly focusing on water bodies. As amphibians inhabit different habitats at different life stages, we combined several methods to assess the potential occurring species (Lüscher and Althaus 2009). The assessment started on 15 April 2018 and ended on 30 June 2018, consisting of six different methods: (1) acoustic mapping, (2) spawn mapping, (3) larvae mapping, (4) newt shining, (5) use of fish traps, and (6) visual mapping, which took place in all four study sites. All six mapping steps were planned to take place at the appropriate time, regarding their developmental stage (Cabela et al. 2001). The acoustic mapping took place once in April and once in May, i.e., during the reproductive season when male amphibians call to attract females (Glandt 2008). In each site, we spent a minimum of 30 min. To map the amphibian spawn, we slowly walked along the banks of the water bodies (for 15 min at each water body) at the end of April. The larvae mapping took place twice at the end of May, using a landing net with a mash size of approximately 2 mm. In small water bodies (< 10 m²) we took five strokes, in medium water bodies (ca. 10–30 m²) we took 10 strokes, in large water bodies (ca. 30–100 m²) 15 strokes, and in very large water

bodies (> 100 m²) 20 strokes. To record the newts, we slowly walked along the banks of the water bodies after sunset and shone lights through the water for 15 min at each water body. In June, four fish traps were cast in each site to catch tadpoles and newts, which were emptied and dismantled the next morning. Visual mapping took place each time we were at the study site for the mapping steps described above.

In all six mapping steps, we determined the species directly at the study site. In doubtful cases, however, we recorded the amphibian calls with an iPhone SE 5 (acoustic mapping), took pictures with a camera (Nikon D90 or an iPhone SE 5; visual mapping), or took samples in alcohol (98% ethanol) for later determination with a binocular (ZEISS, Stemi SV11) and the identification key provided by Thiesmeier (2014). All people involved in the assessment used rubber boots, which were disinfected after each different study site to prevent spreading chytrid fungus or other transmissible diseases (Schmidt et al. 2009).

### Reptile assessment

The reptile assessment took place from 4 June to 15 August 2018, along the banks of the water bodies, at the open parts of the peatlands (here referred to as moorlands) and their surrounding forests, with each site being visited four times during this period. The mapping consisted of a transect leading through the open moorlands and forests, approximately 400 m in length. The observer slowly moved along the previous determined path (transect) for one hour and mapped all visible reptile species along the transect and approximately 2 m right and left of it, following a zigzag pattern (Fitzgerald 2012). The mapping took place in the morning from 8:00 to 11:00 am or in the late afternoon, after 3:00 pm until 7:00 pm, and was interrupted during rainfall.

### Abiotic factors and microhabitats

To characterize and verify the quality of the habitats, we (1) measured the pH value of each water body in the four sites using an HQd Portable Meter (Hach Lange GmbH, Düsseldorf, Germany) and (2) mapped the microhabitats and calculated an indicator species analysis (ISA). ISA is used to identify species characteristics of specific habitat types within the study site. The analysis was performed using the labdsv package in R Studios. Species with significant indicator values ($P < 0.05$) were considered strongly associated with specific habitat types, indicating their potential as habitat indicators. The results were interpreted to identify key species representing different habitat types in the study area. Microhabitats are small habitats with vertical and/or horizontal vegetation and landscape structure in a terrestrial and/or aquatic ecosystem (Ricklefs and Miller 1999). The scale for microhabitats used usually ranges from 25–100 m² (Baraloto and Couteron 2010). Microhabitats were defined based on the habitats provided by Cabela et al. (2001) and the results of Ebhart (2011). We drew polygons of each microhabitat based on the orthophotos of GEOLAND basemap (datasource: https://basemap.at/) and hand sketches of each peatland in ArcGIS 10.6.1 (ESRI) geographic information system (GIS) software to assemble microhabitats and the results of the amphibian and reptile assessments for each study site.

## Authorizations

Two authorizations by the Lower Austrian government allowed us to catch and collect amphibians and reptiles (Provincial Government of Lower Austria, 3109: Stückler S.: BD1-N-200/021-2004; RU5-BE-64/019-2018; Schweiger S.: RU5-BE-64/018-2018; BD1-N-200/021-2004; NÖ-UA-V-30/004-2015).

## Results

### Amphibian assessment

In total, we located 1520 individuals (including larvae and spawn) of eight amphibian species in the study site: *B. bufo*, *H. arborea*, *P.* kl. *esculentus/lessonae* (hereafter grouped and called *Pelophylax* sp. as the distinction in the field is not reliable), *R. arvalis*, *R. dalmatina*, *R. temporaria*, *I. alpestris*, and *L. vulgaris* (Table 2). The species composition and the number of individuals differed in the two main aquatic habitats (peat pools and blocked ditches); in the peat pools, we located *B. bufo*, *Pelophylax* sp., *R. arvalis*, *R. dalmatina*, *R. temporaria*, and *L. vulgaris*. In total, we detected 725 individuals in the peat pools. The most abundant species was *Pelophylax* sp. (416 individuals; 46.3% of total individuals found), followed by *B. bufo* tadpoles (250 individuals; 27.8% of total found individuals). In the blocked ditches, *B. bufo*, *H. arborea*, *Pelophylax* sp., *R. arvalis*, *I. alpestris*, and *L. vulgaris* were identified. In total, we detected 174 individuals in the blocked ditches, again with *Pelophylax* sp. having the highest number of individuals (158 individuals, 17.6% of total found individuals) (see Table 2, Fig. 2).

### Reptile assessment

We located 64 individuals of four reptile species in the study sites: *A. fragilis*, *N. natrix*, *V. berus*, and *Z. vivipara*. In the Schwarzes Moos and the Haslauer Moor, we located three reptile species: *A. fragilis*, *N. natrix*, and *Z. vivipara*. In Schrems we found three species, namely *N. natrix*, *V. berus*, and *Z. vivipara*. Only in Heidenreichstein could we detect all four species: *A. fragilis*, *N. natrix*, *V. berus*, and *Z. vivipara* (Table 3, Fig. 3).

**Table 2.** Results of the amphibian assessment in the four peatlands in the Waldviertel region. Given are the absolute numbers of found individuals. Note that species marked with an asterisk (*) are spawn or larvae.

| Species | Haslauer Moor | Heidenreichstein | Schrems | Schwarzes Moos | Number of individuals |
|---|---|---|---|---|---|
| *Ichthyosaura alpestris* | 0 | 5 | 0 | 0 | 5 |
| *Lissotrion vulgaris* | 0 | 1 | 4 | 0 | 5 |
| *Bufo bufo* | 210 | 8 | 18 | 51 | 287 |
| * *Bufo bufo* larvae | 300 | 0 | 0 | 0 | 300 |
| *Hyla arborea* | 0 | 4 | 0 | 0 | 4 |
| *Pelophylax* sp. | 73 | 205 | 477 | 91 | 846 |
| * *Pelophylax* sp. larvae | 6 | 1 | 20 | 0 | 27 |
| *Rana arvalis* | 1 | 1 | 2 | 1 | 5 |
| *Rana dalmatina* | 0 | 0 | 6 | 0 | 6 |
| * *Rana dalmatina* spawn | 1 | 6 | 0 | 4 | 11 |
| * *Rana dalmatina* larvae | 19 | 0 | 0 | 0 | 19 |
| *Rana temporaria* | 1 | 0 | 1 | 3 | 5 |
| Number of species | 5 | 7 | 6 | 5 | 1520 |

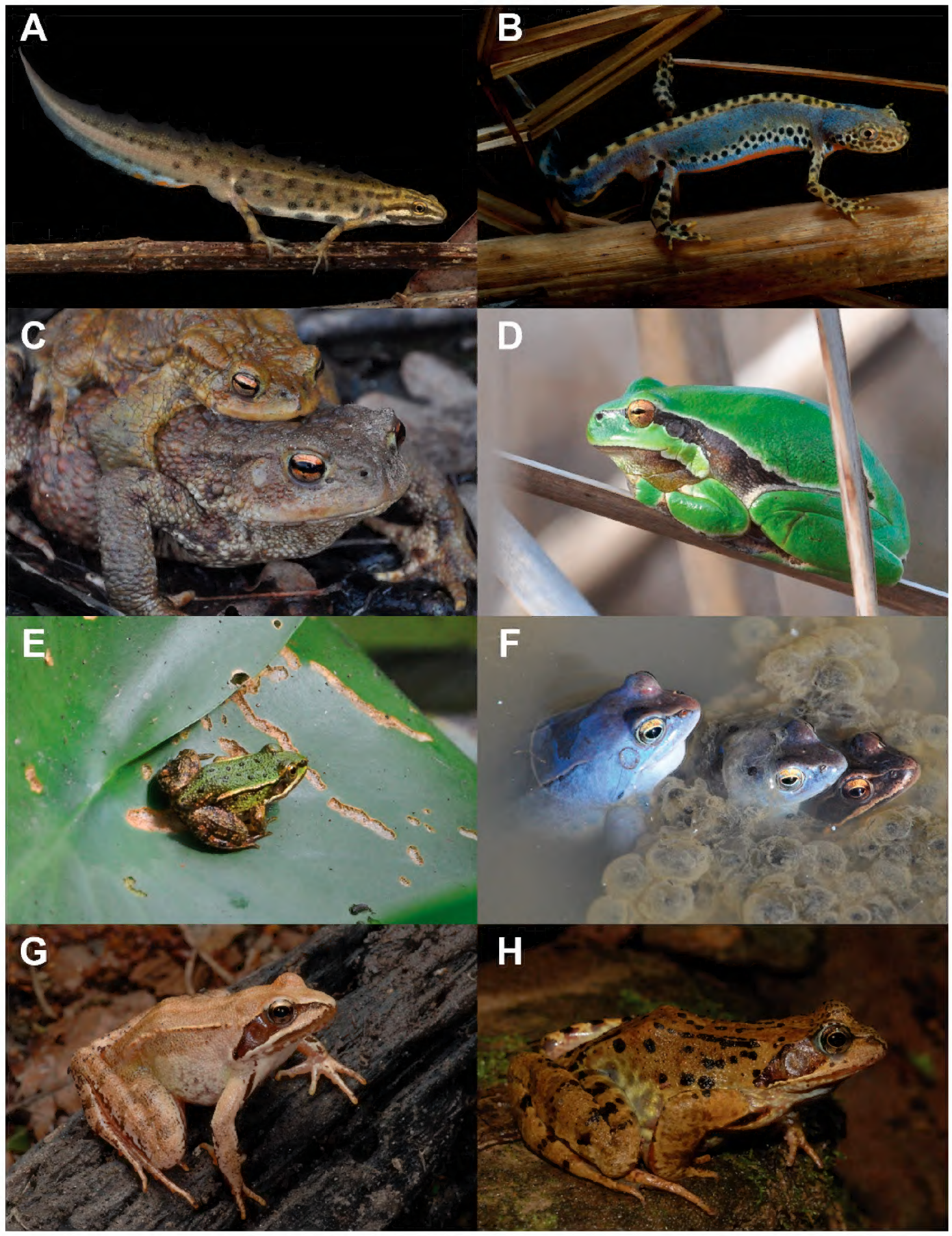


**Figure 2.** Amphibian species observed in the Waldviertler peatlands: **A.** *Lissotriton vulgaris*; **B.** *Ichthyosaura alpestris*; **C.** *Bufo bufo*; **D.** *Hyla arborea*; **E.** *Pelophylax* sp.; **F.** *Rana arvalis*; **G.** *R. dalmatina*, and **H.** *R. temporaria*. Pictures **A, B, G, H** provided by Michael Franzen.

**Table 3.** Results of the reptile assessment in the four peatlands in the Waldviertel region. Given are the absolute numbers of found individuals.

| Species | Haslauer Moor | Heidenreichstein | Schrems | Schwarzes Moos | Number of individuals |
|---|---|---|---|---|---|
| *Anguis fragilis* | 2 | 2 | - | 1 | 5 |
| *Natrix natrix* | 4 | 5 | 8 | 2 | 19 |
| *Vipera berus* | - | 3 | 7 | - | 10 |
| *Zootoca vivipara* | 6 | 7 | 7 | 10 | 30 |
| Number of species | 3 | 4 | 3 | 3 | 64 |

**Figure 3.** Reptile species observed in the peatlands of the Waldviertel region: **A.** *Anguis fragilis*; **B.** *Natrix natrix*; **C.** *Vipera berus*, and **D.** *Zootoca vivipara*. All pictures provided by Michael Franzen.

## Abiotic factors

The lowest pH levels were found in the Schwarzes Moos, while the other three peatlands had higher pH levels (see Table 4, Fig. 4).

**Table 4.** Results of the measurements of the abiotic factors in the Waldviertler peatlands: Haslauer Moor ($N = 4$), Heidenreichstein ($N = 3$), Schrems ($N = 6$), and Schwarzes Moos ($N = 5$).

| Abiotic factor | Haslauer Moor | Heidenreichstein | Schrems | Schwarzes Moos |
|---|---|---|---|---|
| pH (mean) | 6.35 | 6.94 | 7.05 | 3.72 |
| pH (max.) | 6.66 | 7.39 | 9.14 | 4.22 |
| pH (min.) | 6.11 | 6.12 | 5.03 | 3.21 |

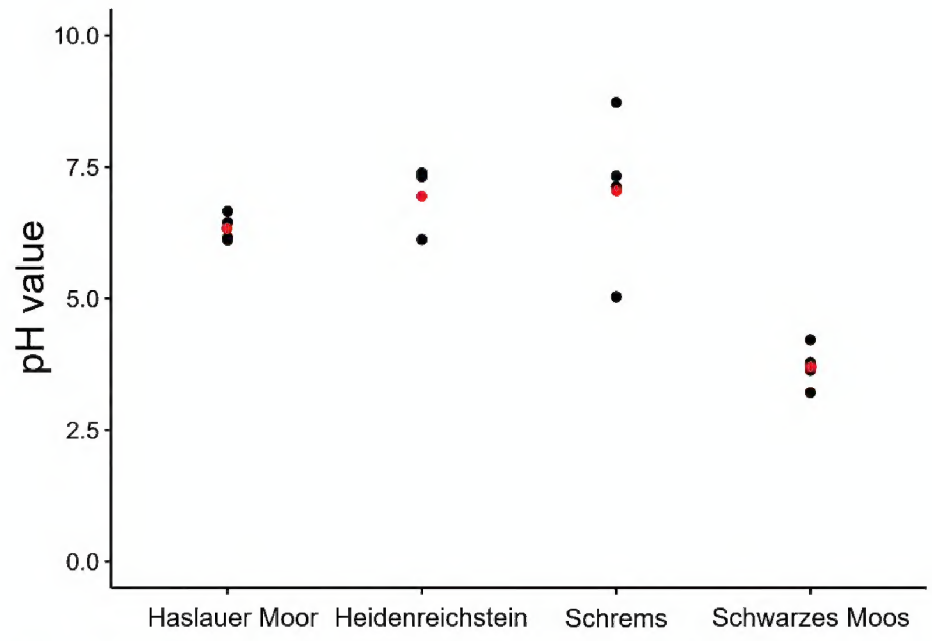


**Figure 4.** Comparison of pH values (visualized as strip charts). The peatlands included in the study site are Haslauer Moor (N = 4 pH measurements), Heidenreichstein (N = 3 pH measurements), Schrems (N = 6 pH measurements), and Schwarzes Moos (N = 5 pH measurements). Each point of the strip chart represents the pH level of a measurement point (black) and the mean value (red). For detailed results, see Table 4.

## Microhabitats

We characterized twelve different microhabitats in the assessment area: open moorland with moss, open moorland with sedges, open moorland with bushes, reeds with water body, water-filled blocked drainage ditch, temporary pond, open water-filled peat pool, silting water-filled peat pool, sparse forest/moor forest, forest, margin, and path (Suppl. material 2). The numbers of amphibian and reptile species ranged from 1–9 per microhabitat type.

The ISA did not show any species with significant indicator values. Although species-specific indicator values were calculated, we did not find any significance for any habitat group, suggesting that no species demonstrated

a strong preference for a specific habitat in our investigation. In general, silting water-filled peat pools were the microhabitat where we found the most species. We located most amphibian species in silting water-filled peat pools and water-filled blocked drainage ditches, and most reptile species in open moorland with moss, open moorland with bushes, and on paths. We observed *Pelophylax* sp. in nine, *N. natrix* in seven, and *Z. vivipara* in six different microhabitats, whereas *I. alpestris* only in water-filled blocked drainage ditches (Fig. 5A–C).

# Discussion

## Amphibian assessment

Our results show that blocked ditches and peat pools provide aquatic habitats for eight amphibian species. We found higher numbers of individuals in silting water-filled peat pools than in blocked ditches, which might be related to heavy siltation and desiccation of the ditches (Remm et al. 2018). We observed all expected amphibian species in the study site: *I. alpestris*, *L. vulgaris*, *B. bufo*, *H. arborea*, *R. arvalis*, *R. dalmatina*, *R. temporaria*, and *Pelophylax* sp., but we did not locate all expected species in each peatland. *Bufo bufo*, *Pelophylax* sp., and *R. arvalis* we recorded in each peatland. *Bufo bufo* and *Pelophylax* sp. are very common species with low habitat requirements and are widely distributed across Austria (Cabela et al. 2001). *Rana arvalis* occurs across the Eurasian subcontinent but is limited in Austria to the eastern and southern lowlands (Glandt 2008). Spawn and larvae of *R. arvalis* are more resistant to acids than other amphibian species and therefore able to inhabit acidic peatlands (Räsänen et al. 2003; Burmeister 2015). We found several amphibian species in low abundances: *I. alpestris*, *L. vulgaris*, *R. dalmatina*, *R. temporaria*, and *H. arborea*.

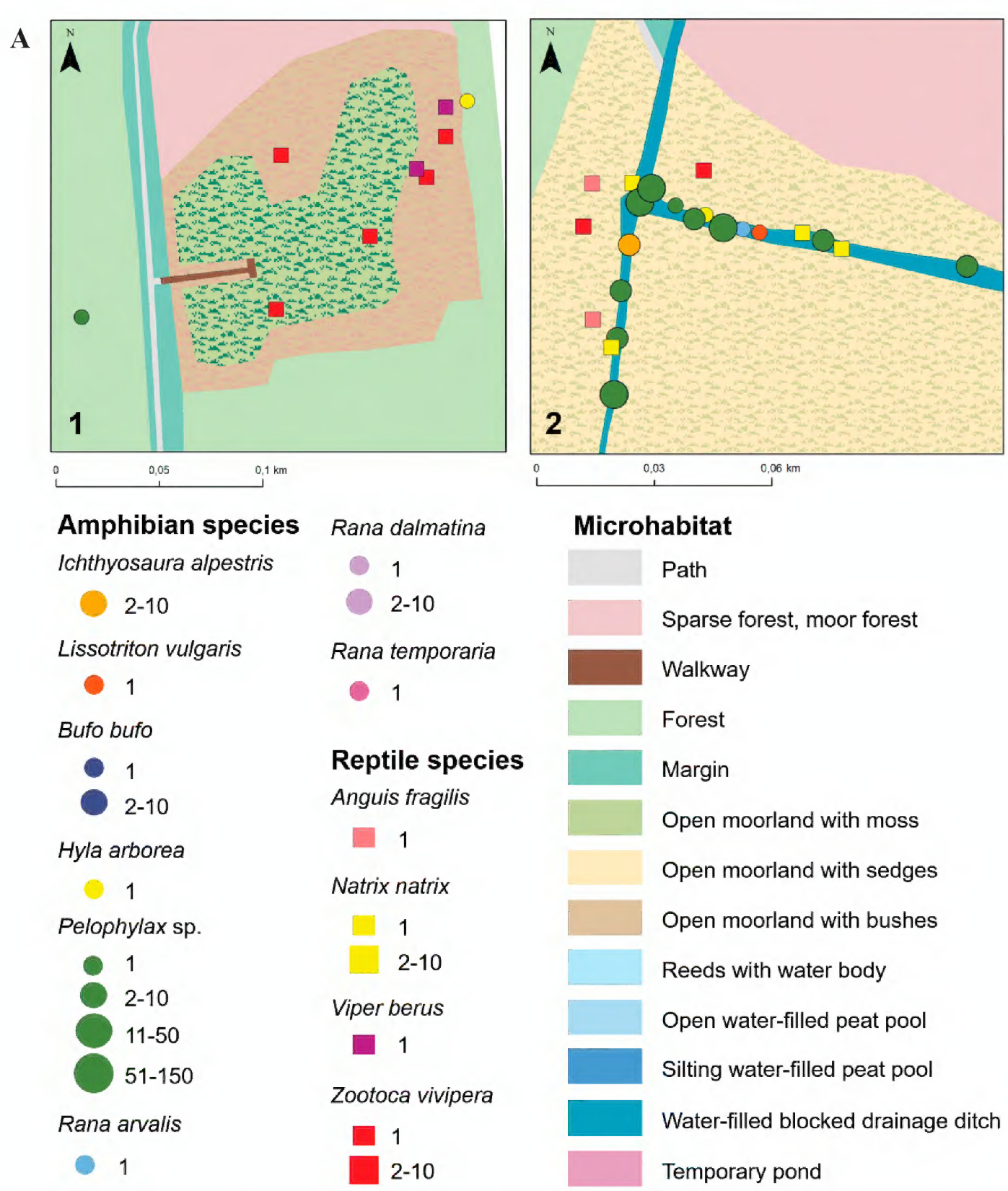


**Figure 5. A.** Microhabitats and amphibian and reptile species in Heidenreichstein (1: open moorland; 2: drainage ditch). Circles represent amphibian species; squares represent reptile species. Note the different scales; **B.** Microhabitats and amphibian and reptile species in 1: Haslauer Moor and 2: Schwarzes Moos. Circles represent amphibian species; squares represent reptile species; **C.** Microhabitats and amphibian and reptile species in Schremser Moor (1: large water-filled peat pool; 2: open moorland and a silting water-filled peat pool). Circles represent amphibian species; squares represent reptile species. Note the different scales.

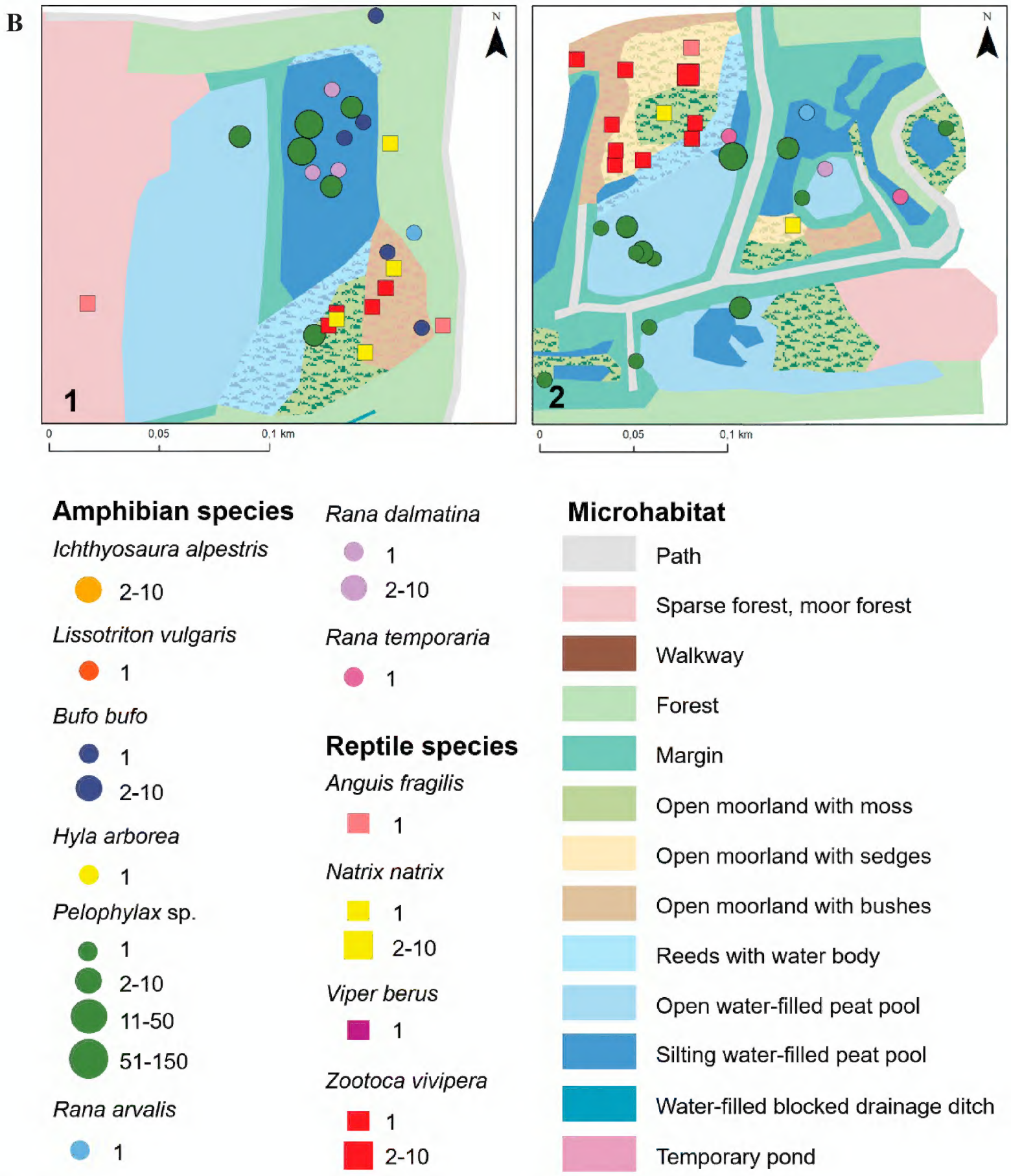


**Figure 5.** Continued.

In the Schwarzes Moos, we recorded the lowest pH levels ranging from 3.2–4.2 (Table 4); nevertheless, we observed calling *B. bufo*, *Pelophylax* sp., *R. arvalis*, and *R. temporaria* and located *R. dalmatina* spawn in peat pools. Mortality of many amphibian species increases when pH levels are below 4 (Pierce 1985). Dolmen et al. (2008) reported that low pH levels cause the absence and extinction of amphibians in Southern Norway: pH levels of 4.5–4.6 are critical for *R. temporaria*, 4.7 was the lowest pH level recorded for *B. bufo*, and 4.8 for *L. vulgaris*. Successful reproduction was not observed below 5.2 and 5.3 in *R. arvalis* and *Triturus cristatus* (Dolmen et al. 2008). However, pH levels of water bodies are subject to certain fluctuations in relation to, e.g., rainfall (Fraindová et al. 2022); therefore, a more comprehensive abiotic investigation of the water bodies on a long-term basis across the year is necessary to provide more detailed insights into the relationship between pH value and the amphibian fauna in the peatlands and its ecological role. Secondly, a more intensive assessment and an adjustment of monitoring methods might have been necessary to find species that are harder to detect. The two expected newt species (*I. alpestris* and *L. vulgaris*) do not call to attract females (Thiesmeier and Schulte 2010; Große 2011), which hampers localization. The use of more fish traps and additional newt-shining surveys could have helped to detect both species in higher numbers in all four peatlands.

## Reptile assessment

Our study verified four reptile species in the Waldviertler peatlands, located mainly in open moorland habitats and on paths. During the reptile assessments that have been carried out at temperatures ranging from 18–27 °C, the most frequently observed reptile species was *Z. vivipara* (Table 3).

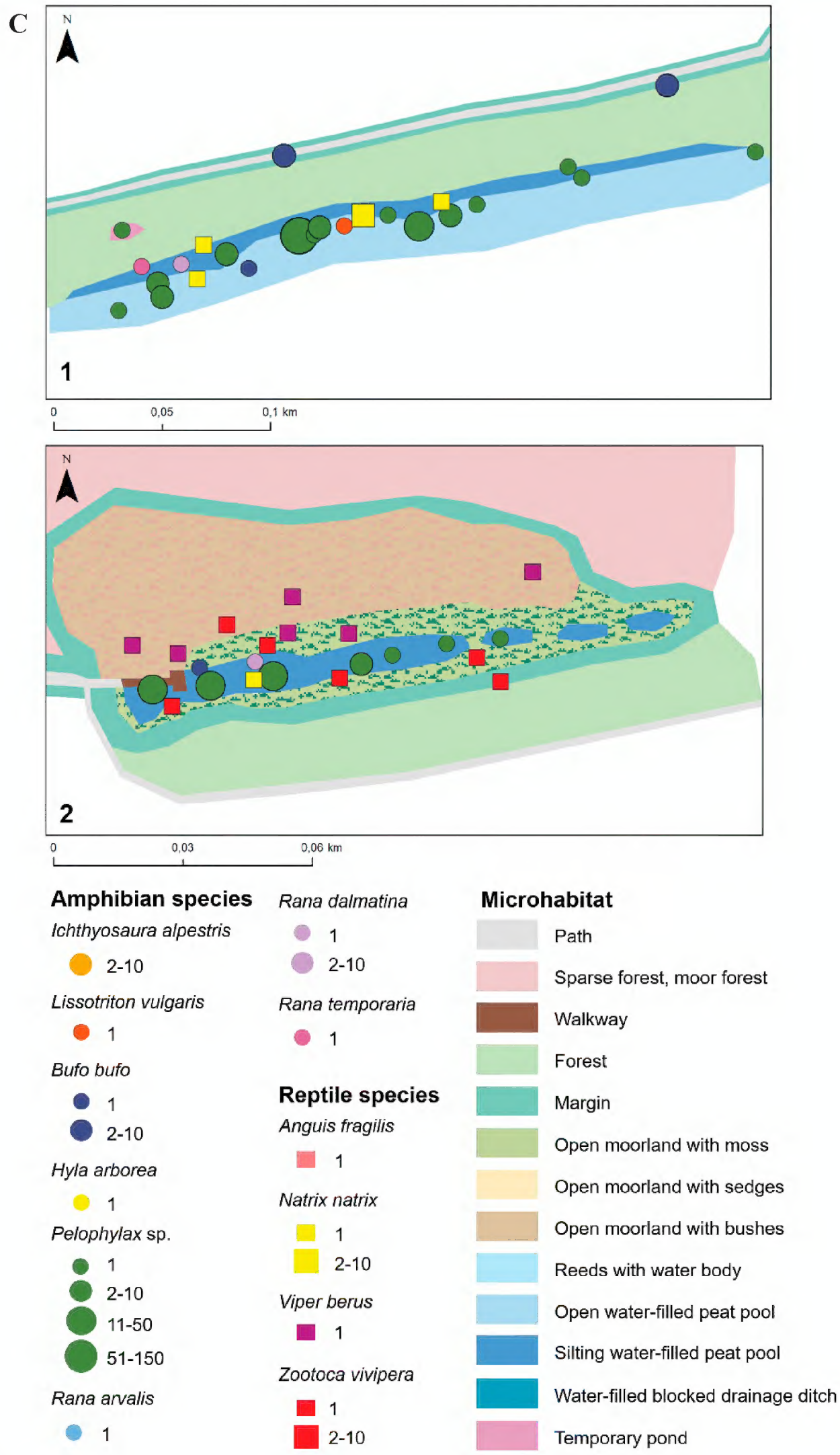


**Figure 5.** Continued.

We located *Z. vivipara* in all four peatlands, with the highest total number of individuals of all recorded reptiles. *Zootoca vivipara* also uses aquatic habitats, mainly to escape from enemies, and can submerge for up to 20 min (Thiesmeier 2013). On hot summer days, *Z. vivipara* relocates to wet and humid areas (e.g., dense understory) to prevent water loss through transpiration (Buschinger and Verbeek 1970). Similar to these observations, we also located most *Z. vivipara* between wet moss cushions in open moorlands.

The second most abundant species located in the study site was *N. natrix*, which we could verify in each peatland. The species is often found near water bodies, likely because *N. natrix* feeds mainly on frogs (*Pelophylax* sp., *B. bufo*, *Rana* sp.) (Filippi et al. 1996). The second snake species located in the study area was the Adder, *V. berus*. In Austria, *V. berus* occurs in the montane-alpine region and in the Bohemian Mass in the north of the country. In the latter area, *V. berus* mostly occurs in wet meadows and peatlands (Cabela et al. 2001). *Vipera berus* prefers high temperature variations between day and night, short vegetation periods, high precipitation and/or humidity, and structure-rich habitats (Völkl and Thiesmeier 2002).

In peatlands, *V. berus* needs structures that heat up quickly (Otte et al. 2020). Consistent with these findings, we mostly found *V. berus* next to dead wood, on moss pads, or between high grass in open moorlands. We did not assess all reptile species that were expected in the area. To estimate the total reptile diversity in the peatlands, further investigations are necessary.

## Conclusion

This study provides a first amphibian and reptile assessment in the peatlands of the Natura 2000 area 'Waldviertler Teich-, Heide- und Moorlandschaft' in the Waldviertel region. Here, we show that peat pools, drainage ditches, and open moorlands are important habitats for amphibians and reptiles, species that are threatened all over the cultural landscape (Nöllert and Nöllert 1992). These microhabitats are uncommon in the cultural landscape of Austria, as they are created when former peat-worked peatlands are restored. In the future, peat pools and drainage ditches will silt up as a result of natural succession, which leads to the question of whether the peatland water bodies can persist in line with the aims of the peatland conservation. Clearing of drainage ditches and removal of bushes and shrubs along the ditches are effective conservation measures in drained peatlands, increasing brown frog colonization (Soomets et al. 2017; Remm et al. 2018), which at least partially could be considered in the conservation management plans of the Waldviertler region.

The conservation management in the Natura 2000 site mainly aims to rewet the peatlands, stabilize the water levels by damming the drainage ditches, and attain the natural climax stadium, which in the south of the Waldviertler region are moor forests (Ebhart 2011). The restoration of peatlands created habitats for many endangered amphibians and reptile species. Habitat loss, landscape fragmentation, over-exploitation, invasive neobiota, pollution, diseases, and climate change endanger amphibian and reptile species across the world (Gibbons et al. 2000; Stuart et al. 2004), demonstrating the importance of maintaining and creating near-natural aquatic and terrestrial habitats with low levels of disturbance to protect and preserve local amphibian and reptile fauna.

## Funding

The study was financially supported by the Land Niederösterreich (TOP Stipendium to SST) and the Natural History Museum Vienna.

## Author contributions

Conceptualization: SST, SS; Methodology: SST, SS; Data collection: SST, RS; Analysis: SST; Resources: SST, SS; Data Curation: SST; Writing—original draft: SST, RS, SS; Writing—review and editing: SST, RS, SS; Visualization: SST, RS, SS; Supervision: SS; Project administration: SS; Funding Acquisition: SST, SS.

## Acknowledgements

We thank the Natural History Museum Vienna, especially the Herpetological Collection, for their support. We thank Walter Hödl, Axel Schmidt, Günther Wöss, and Harald Zechmeister for the valuable discussion. Further, we thank Marie-Therese Fischer, Gabriela Dangl, and Joachim Rigler for helping in the field.

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# Supplementary material 1

## Raw data

Authors: Susanne Stückler, Ria Sonnleitner, Silke Schweiger
Data type: xlsx
Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.
Link: https://doi.org/10.3897/herpetozoa.37.e130028.suppl1

# Supplementary material 2

## Description of the microhabitats defined in the Waldviertel region

Authors: Susanne Stückler, Ria Sonnleitner, Silke Schweiger
Data type: docx
Copyright notice: This dataset is made available under the Open Database License (http://opendatacommons.org/licenses/odbl/1.0/). The Open Database License (ODbL) is a license agreement intended to allow users to freely share, modify, and use this Dataset while maintaining this same freedom for others, provided that the original source and author(s) are credited.
Link: https://doi.org/10.3897/herpetozoa.37.e130028.suppl2